Ground Improvement
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Module No. # 05
Lecture No. # 13
Dewatering - II

I would be continuing my previous class here; we will be talking about dewatering. In the previous class, we studied on the principles of dewatering, why why we should do the dewatering? Essentially this is because we need to remove the water and then make it possible for construction to proceed in the for foundations.

Essentially for dewatering, we should be able to understand the hydrogeology of the area as I just mentioned. The aquifers we have, in fact, we studied this in under you know our under graduate curriculum, in which you have two types of aquifers, one is a confined aquifer, the other one is unconfined aquifer. You also have perched water table, where the water tables exist in some localized areas.

And so, one should be would understand the hydrogeology of the area and also the permeability, because this is an important parameter for design. And also, what is the design issues like how much of water should be excavated, removed so that that area is little free of water and you can go ahead with the excavation and also see that the excavation is stable.

So, in the process of excavation, one should make sure that the water is removed and also it is stable.

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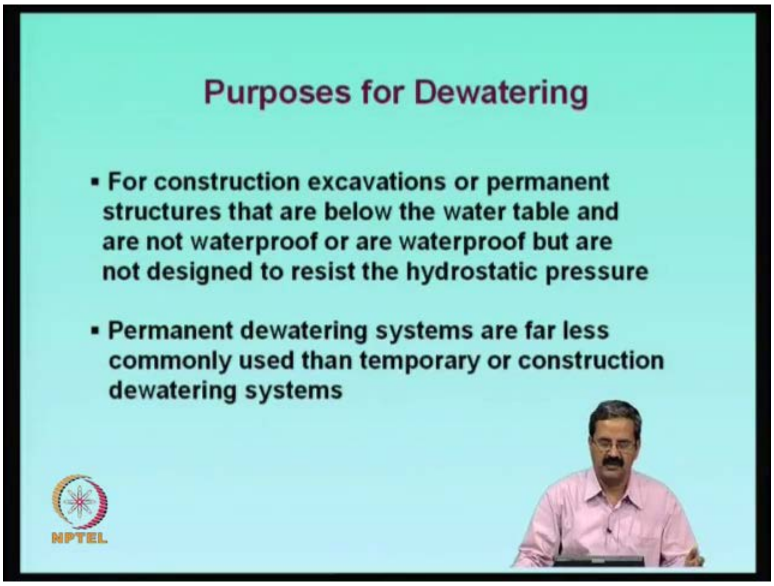

So, these issues we should address and we as just I would like to take a few minutes to recap what we did, what we understood. We need this a a for essentially, for construction of excavation some when you are trying to go for structures below the water table. And sometimes the permanent dewatering systems are very expensive, normally we go for temporary excavation systems, and we also try to have some measures to release a hydrostatic pressures generated.

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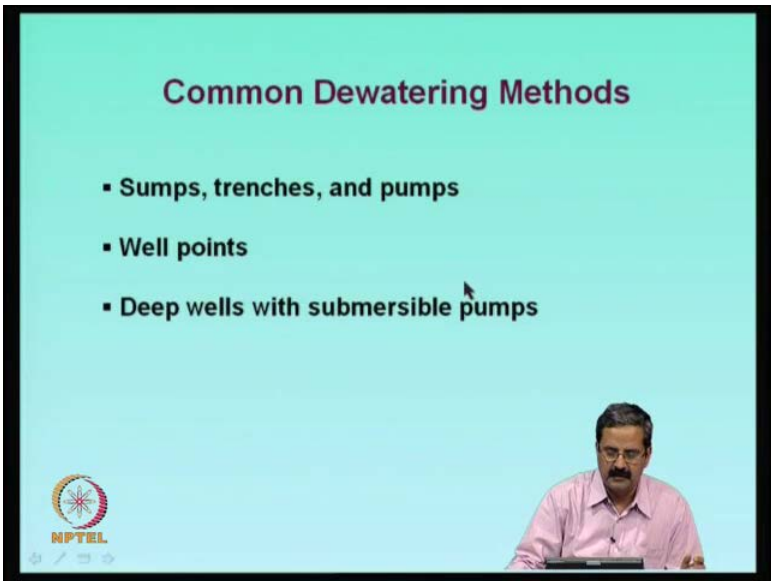

We have varieties of equipment that we use, we need to have sumps, pumps, trenches well points, deep wells and all that.

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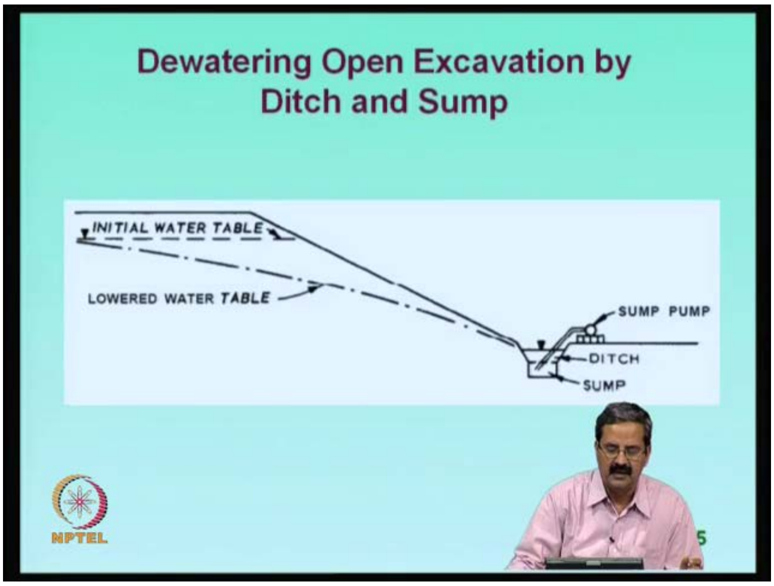

And this is a typical example in which one can lowered the ground water table, like this is initial water table and then by having this short of pump and arrangement in a ditch and all that, one can lower the ground water table.

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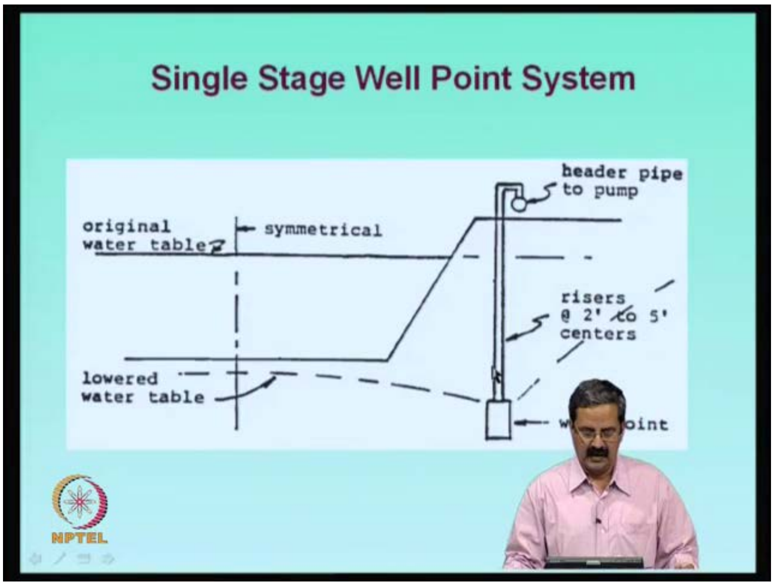

this is another one, which is which we call it as well point system, in which again there is a water table here, because of this well point here, we are trying to lowered the water table from here to here and this is the bottom of the excavation. So, at least about one or two feet below the water should below the foundation level the water should be drained off.

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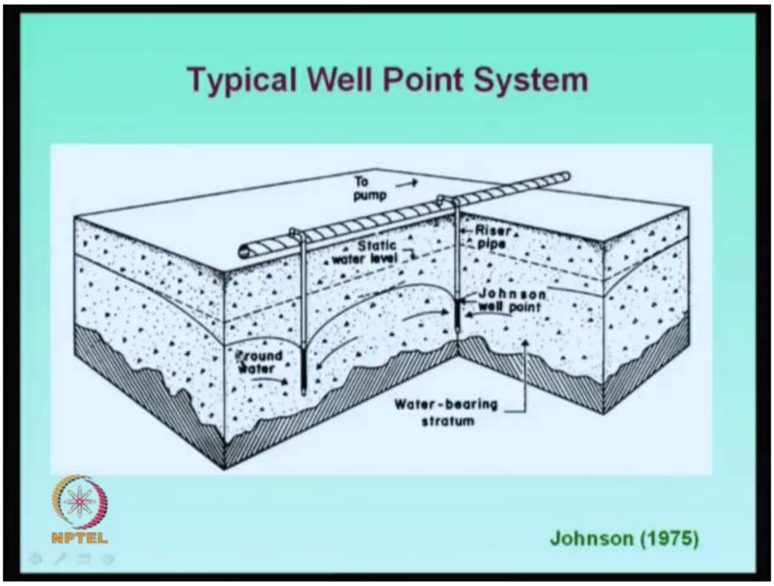

This is a typical system in which you have headers and all that.

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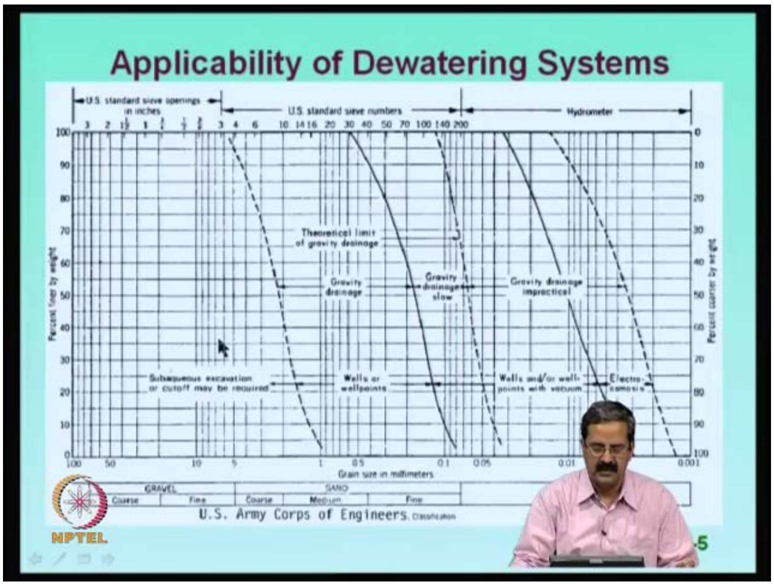

And this is an example that I just discussed, the this is in, this shows you the applicability of the different types of ground water dewatering systems. Depending on the greater distribution characteristics one can have these systems like, say for example, if you have a very fine material, it will have electro osmosis, which will discuss in a short while.

And also if you have the grain sent distribution, in say for example, 0.01 to 0.06 or 0.07 range, one can go for gravity drainage like you just go to the lowest point and start will joining the water. So, by gravity and by the other force, it will, water will collect at one point and then one can remove the water. So, this is an important thing, because one should understand, which what types of soils are suitable for drainage and what type of drainage one can have.

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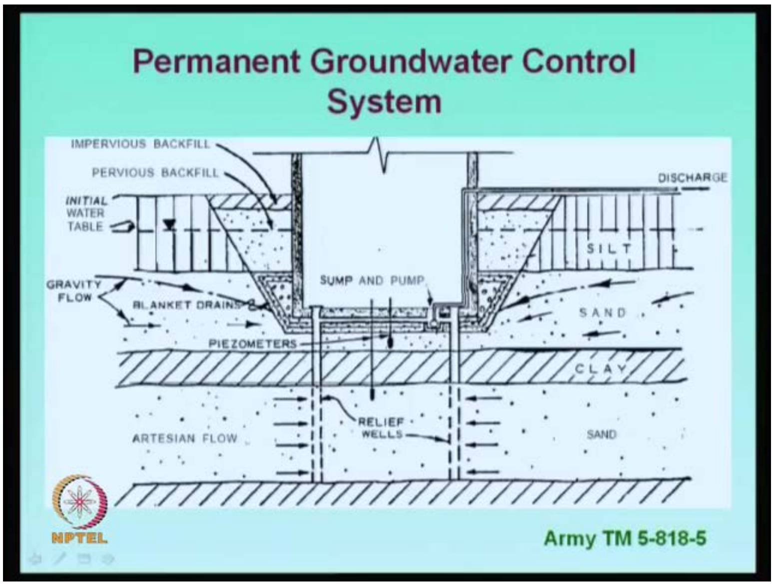

So, for example, in clays, we cannot have gravity drainage, this is some short of applications in which you try to really reduce seepage pressures beneath the foundations, like sometimes extensive instrumentation is also placed, like pyrometers we have. What happens is that, if this is an excavation, the possibility is that, if this is initial water level, there is a water pressure that comes in this passion and if you are able to release that water pressure in some sense, like putting the water pressure to nearby aquifers and also have a release system here, then its fine.

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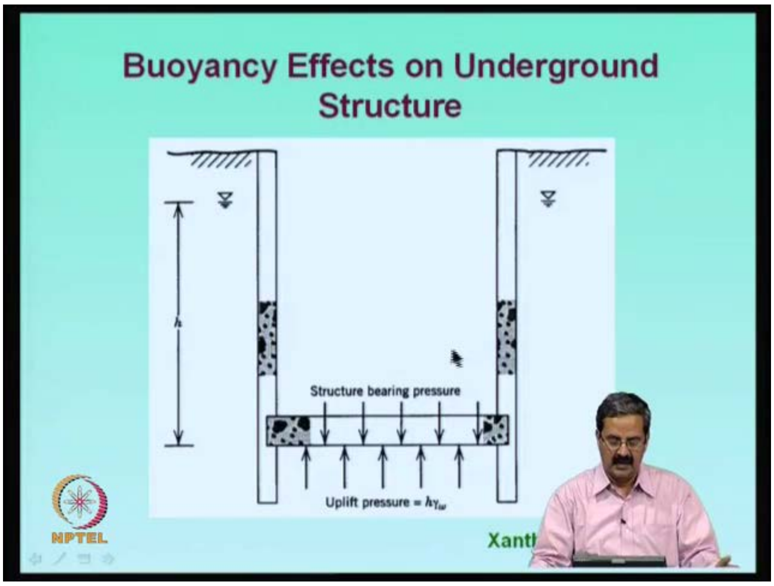

This is a typical field situation that we come across, that we should always design. You know, say for example, if you have an underground structure, you may have to design for some of uplift pressures here that are generated, in fact, this is this this results in a very expensive designs in the sense that thickness of the raft or whatever, foundations that you are going to have would be very thick compare to the other loading conditions, so we should, this is some of the typical cases that we have seen.

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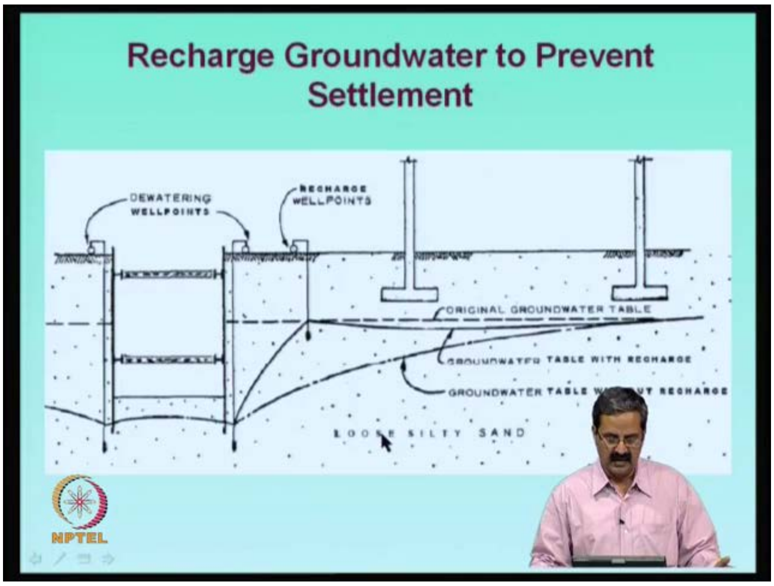

And this is a typical ground water lowering scheme next to the building, suppose you have a, see the thing is that, if you try to devote a lot, there is a possibility that there is a different settlement, because ground water lowering results in increase in effective stress. And what happens is that, if there is increase in effective stress, is that there is a settlement that takes place, so sometimes before you you try to have a system wherein you try to withdraw the water, at the same time you try to pump back the water in such a way that you do not have a appreciable difference of the effective stresses between this foundation and this foundation. So, it is not easy, so you have well a point system here, but again you have a recharge point here also.

So, you have a, you must be able to design your system in proper way such that you are able to lowered the ground water table, but also recharge next to this foundation. Say for example, you have a recharge point next to this, close to this foundation, though this two well points are trying to remove the water from this area, there is one pump, that is one the point, wherein you are trying to pump in lot of water in such that the effective stress between these two foundations is not very different and then you know so that it does not lead to lot of settlements.

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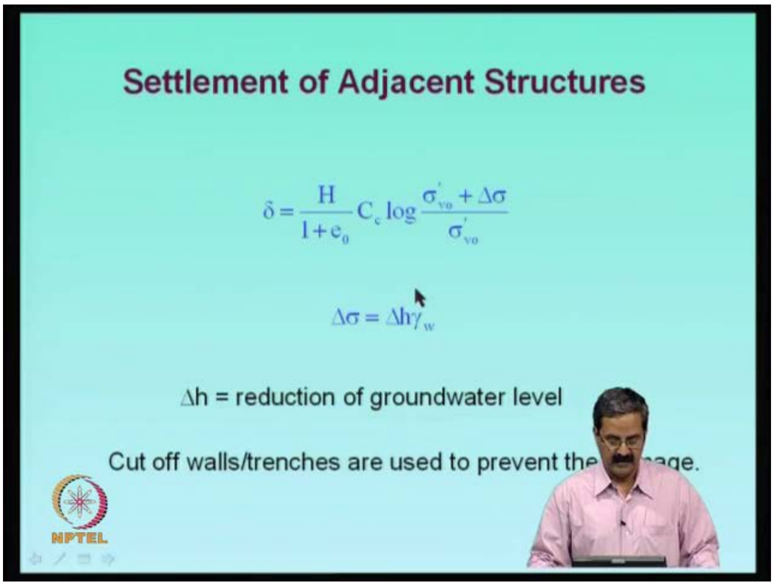

Sometimes this is the way that we calculate the different settlements, that we are already we know about this and sometimes we use cutoff walls and trenches to prevent a damage.

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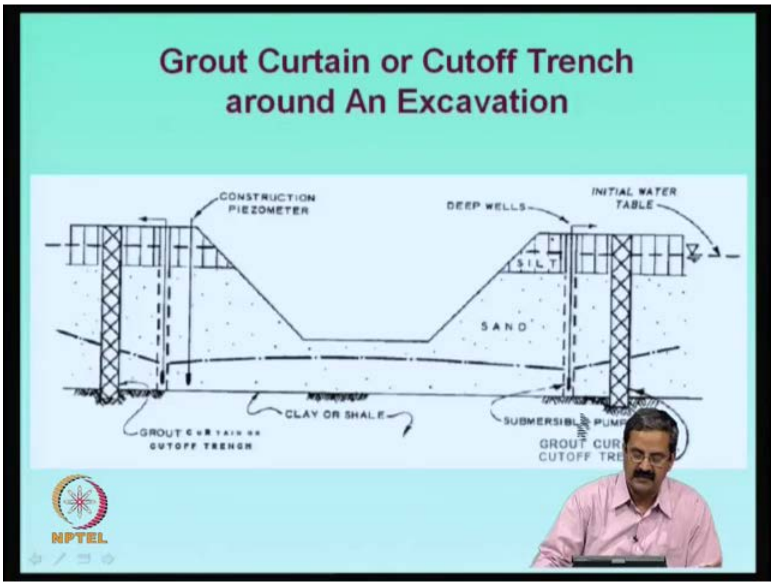

For example, You can have, you know you are trying to have a dewatering system here, deep well here and then you have removed the water table- water level from top level, to say for example, from here to from this point and it is always better to have some sort of cutoff trenches also.

Because the cutoff trenches or cutoff grout curtains we call them, they are little more impermeable compared to the soil. The soil or an aquifer is essentially a sandy system, in which the permeability is going to be high, the moment you make this well point system, there is a tendency for the water to rush back and then see that the ground water comes back to the original condition, but we do not want that. What we try to do is that, this area is free of water, but at the same time, we do not, we would like to interest this flow line by putting this sort of a curtain, which is something made of impermeable materials like it can be even betonies, it can be geomembrane, it can be a cement slurry and all that.

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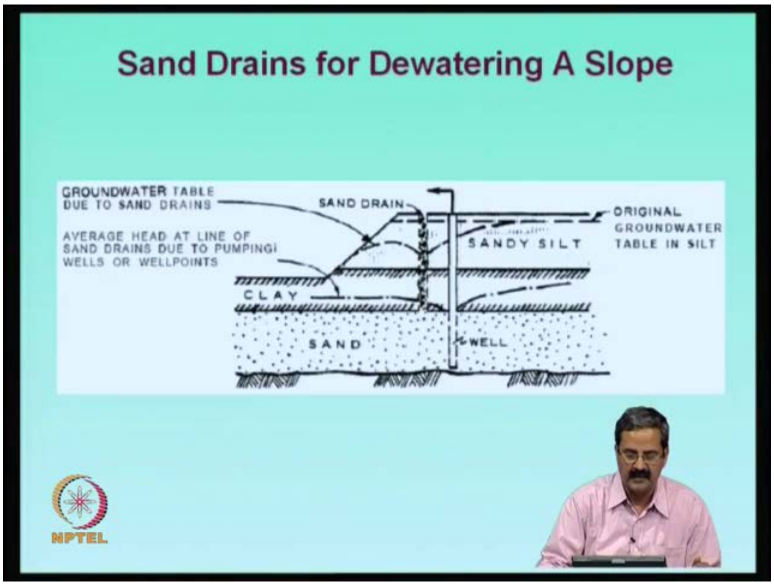

This is another interesting system, in which, say for example, one can lower the ground water table next to the slope. So, there is a well here and then you also can have a sand drain here, such that this is also connected to the aquifer here, so what happens is that, once it is connected with the aquifer, the possibility is that all the water goes down here, and the pore pressures are not mobilized very you know. So, the pore pressure is somewhat released, they it is taken to you know atmosphere, so that is what it means, that it is it it is serving as a protective system.

Actually in this context, I must give an example that there is one area, where you know I am just trying to understand one case study, wherein there was a particular bus stand area, where you know there is lot of water logging in that particular place. And then people wanted to, you know within the before a minister visits that area, they wanted to keep that area you know completely dry. And you know we we normally in some in Indian context, we use all low lying areas for certain bus stands or certain important locations, but then you always see that the art always a water logging is a problem.

So, what the the solution there was that, the field engineering was wise enough, he wanted to dewater the whole area, but he he did a survey of what is the hydrogeology of the area, when he looked at it, he saw that there is a permeable stratum like this, you know well well you know it is a sandy layer exist about say ten meters down.

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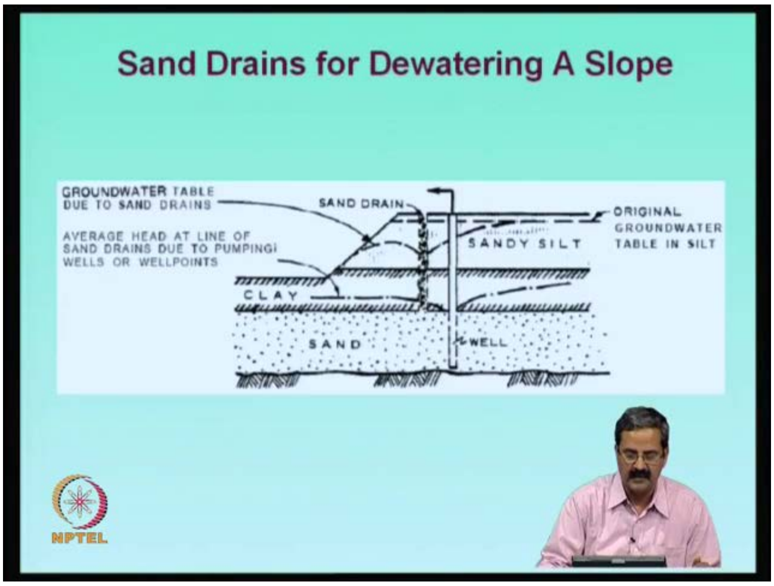

So, what he did was that, imagine that these all are area that is close to a bus stand or something like that, but then there was a water logging because of the presence of water table close to the ground water table, close to the ground surface. So, what he did was exactly that he just took a, made it hole like this, put some geocentric drains, prefabricated vertical drains and connected them to the sand drains, sand sandy layer that existed here, with result that he with a proper spacing and all that, he was able to connect the whole bus, the area which was water log to the sandy layer that existed below and may be within a two two one or two two days, the whole area that was suppose you got a logged, it was it totally drained off. So, it was an interesting example that I must mention, that effective understanding of the hydrogeology of the area coupled with proper understanding of the problem helps in giving a good solution, which is cost effective.

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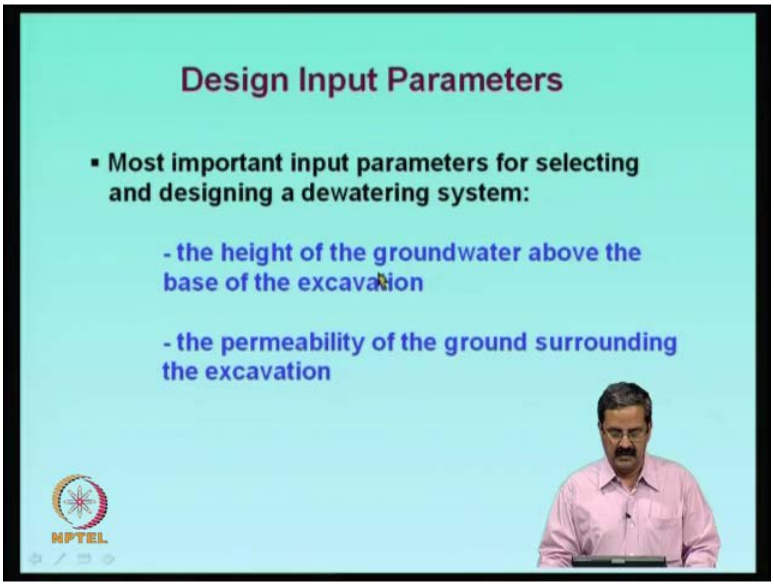

So, when you are trying to design a system like groundwater dewatering system, you must be able to know what should be, what height of the groundwater table above the excavations is. For example, you have the bottom of the excavation minus ten meters and if the water table is minus five meters, you must be able to dewater five meters.

And then, if you want to dewater, only the permeability of the ground is important parameter and we saw that number of methods are there to find out the field permeability. In fact, one must only use a felid permeability test, because a laboratory test are quite, could be misleading, because the you may not take samples properly and all that. So, one should do pumping system test or even packed test to find out the field permeability and use that in the design.

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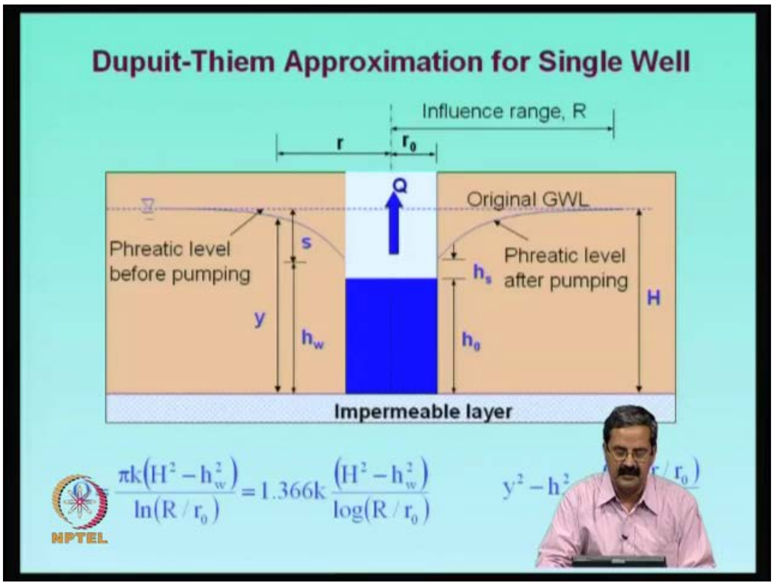

In fact, this is one single well approximation, in which if you want to this is you know the discharge and if you know the height of the up to the impermeable layer, then this is the H naught is the height. And so, you have this sort of expressions, which we studied in undergrad courses in irrigation engineering and other subjects, where you know how to make the discharge calculations if you have a wells, you know where this is a standard problem, in which you will have this particular… This is a the prelatic line after pumping and so this this is prelatic line before pumping, because of the withdrawal of water it comes down to this level, so these are all the various variables involved and you can get the discharge.

And then that also like, you know if you are able to have two wells successively, one can use level difference in the two wells to measure the permeability as well, this we discussed.

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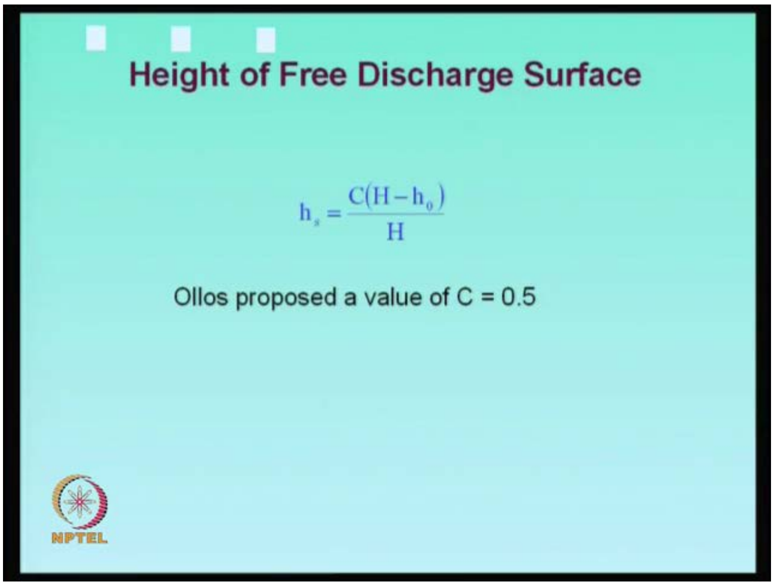

And there are certain expressions here, see for example, in the previous case, this h s is known as the height of free discharge surface and there are some relationship H minus H naught divided by h into c. Like essentially there is a sort of little above, you know there is a what degree of you know there is a water layer exists you know not exactly close to the prelatic line, that we see not exactly like this, but there is h s you know layer at which it can be wet and this is an important factor.

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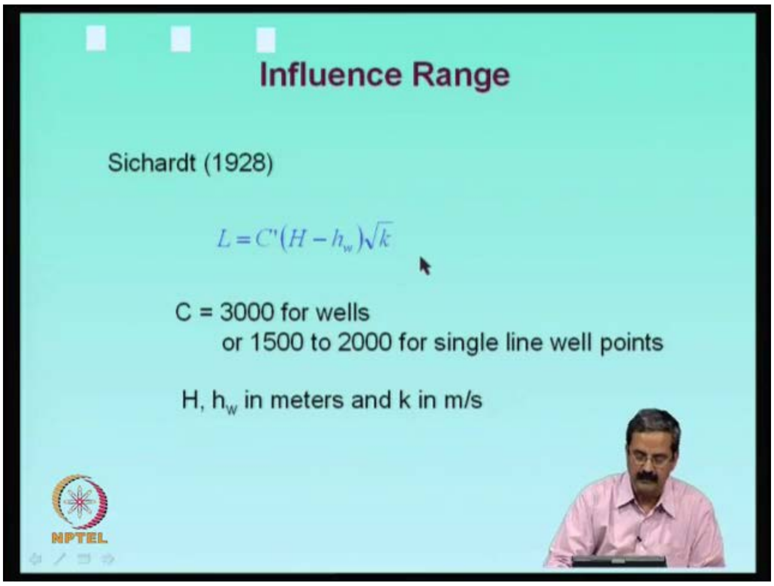

And to find out the influence range like the length at which, the the area over which one can the dewatering system is going to be effective, one should have the understanding of what is the length of the area or the area of the areal extent. So, there are some expressions available in literature, which are little empirical, but then there is no other way here. So, there are some empirical relationship given in this expression, which is related to the height and also the square the permeability of the soil and also the the free height.

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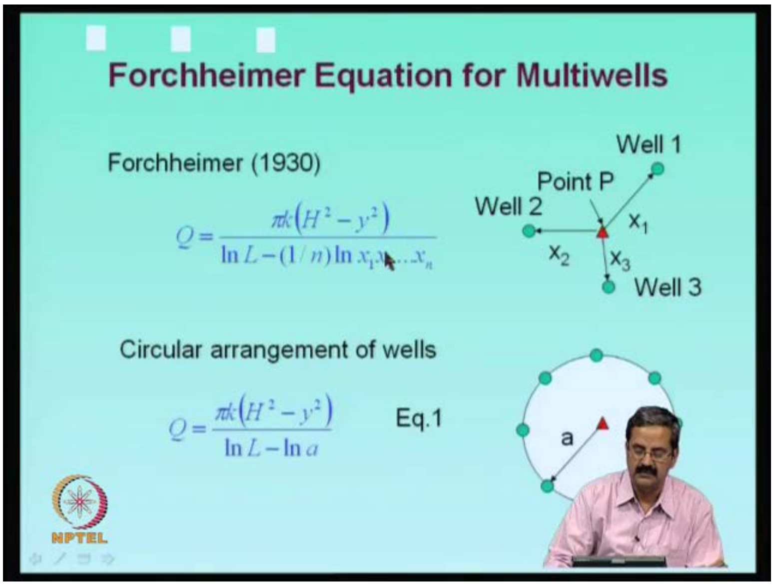

So, this is expression that I was just mentioning as the I just enter at this point, where one one if you have one well point, one can calculate permeability. So, we have a number of wells 1, 2, 3 or n, it could be n and you have a calculation of the discharge, one can use this x 1, x 2, x n of the distances of the wells and l is a influence area. So, one can think of a circular arrangement of the wells and the expression is in this form, like where a is a area, radial distance of the well point.

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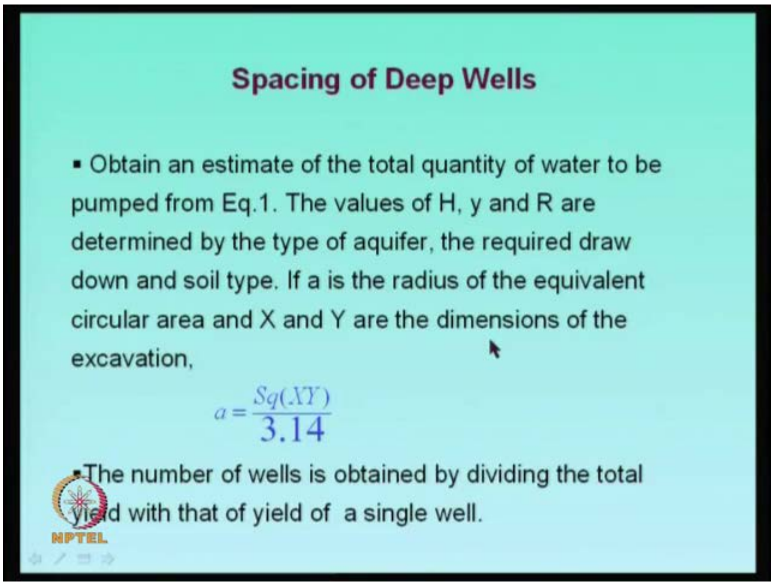

So, this is an important expression, and one can how do you really now, suppose there is a an apartment area which is trying to come up in the you know dried leg belt you know, but still there is always a possibility of you know water table exists there, you would like to construct apartments, and you would like to go for basement flooring, and there is some sort of construction that you need to take up. So, how do you get all these parameters? We will see how do you get this spacing, is something that we should get the total quantity of water to be pumped. Say for example, this is an equation that I have given, so the suppose imagine that this is a circular area and then this is a discharge that you have from, so many number of pumps one that have, some five pumps, eight pumps here. So, if they are all radically distributed with a radius a, you will have discharge from this expression like this, these all given in a standard text books, particularly (( )) and other books can one can see.

So, what we do is that, we should be able to get the optimal estimate or the some estimate of the total quantity of the water to be pumped. The values of height height of that this thing and y is another variable and r are the r or l actually to be determined by the type of aquifer, the required draw down and the soil type.

If a is the radius of the equivalent circular area and x and y are the dimensions of the excavation, you get square root of, say for example, 10 meters by 20 meters, so square root of that divided by pi.

So, this gives a circular the diameter or the radius of the equivalent circle and so we know that you can get the total quantity and you know the you can also have the expression for single well. So, knowing that you just get the number of wells, so this is what we do, I will just give some example also on that.

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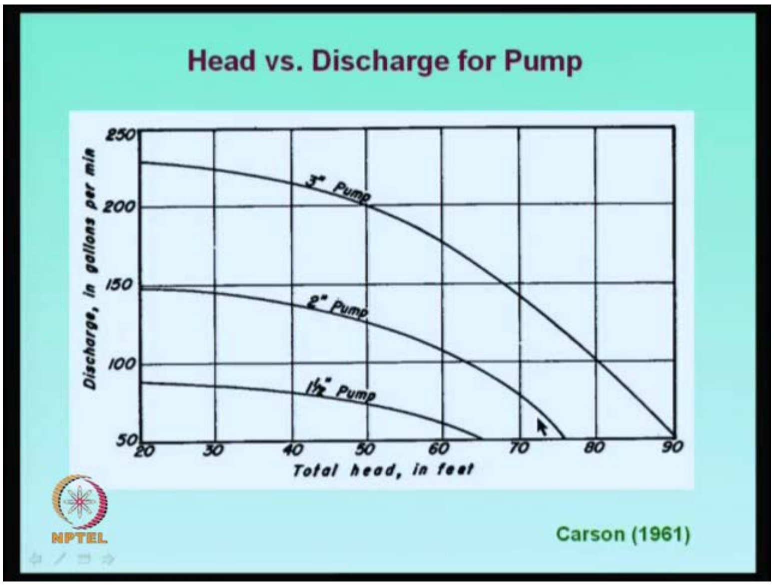

In fact, so once you know the you have different types of pumps also, like you know for example, in India, Kirloskar, there are so many companies; one can have lot of information from these pumps industry. And depending on the diameter, and they they have different, these pumps have different capacities, discharge capacities as well as the heads they can handle. So, you can see that a three inch pipe is sufficient to handle, I mean, it can handle heads up to 90 meters and then it can give a discharge in terms of so many gallons per minute. So, this sort of one should understand, you know actually the company will give you this sort of information and many of the companies they will have their own information. So, I mean they have their own, lot of experience connected with this.

And this is another type of expression, same thing of course, higher one's like the what I showed you was lower pump, lower size, this is 3 inches, four inches, 6 inches and 8 pump size, you can see the discharge capacity is very high, like even fifteen hundred, eighteen hundred gallons per minute and then head is also like… and for the same head.

So, one can really have a good, one should the choice of pumps, is also an important parameter here.

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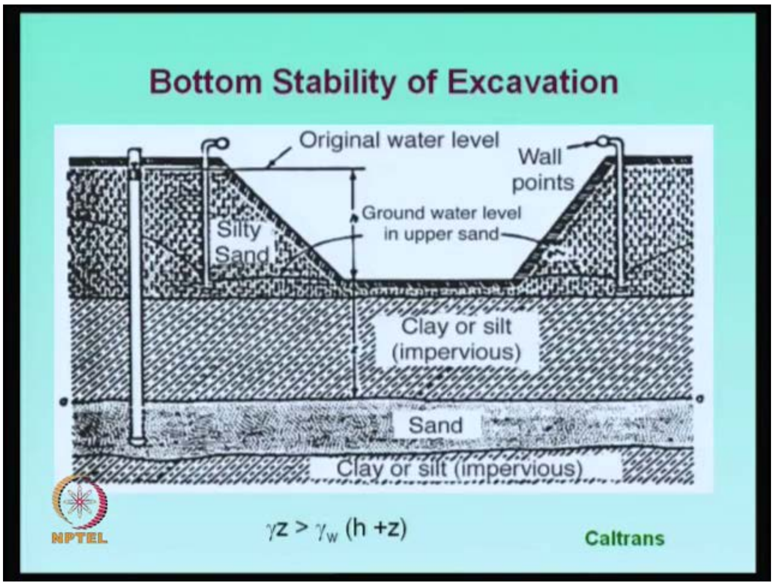

And of course, this is another example of the bottom of how do you avoid the bottom of the (( )), you know, in fact, what happens if you just do the ground water lowering, the possibility is that the water gets, you know there is uplift here.

And so we try to really release a pressure to this point, say for example, we can see that this is the blue line, you can see that, so you need to see that this condition is like, the total stress at a particular point is more than the water pressure plus this is actually unit rate of water into the height plus the z. You know the depth of this thing, so one should take care of these conditions.

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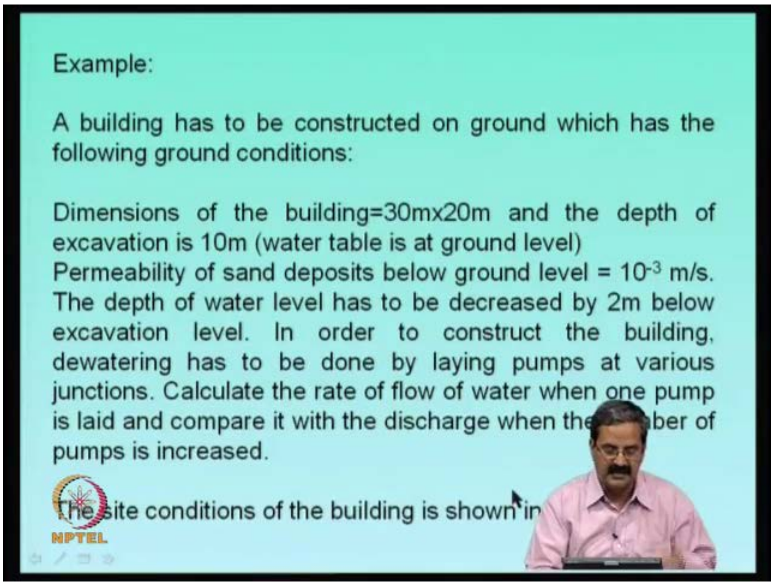

I just want to give a small example here. Anyhow the you have a building to be constructed on ground, which has the fallowing ground conditions. Dimensions of the building is about thirty to 20 meters is a you know plan area, like you can say this is 30 meters, this is 20 meters and the depth of excavation is ten meters, you have to go down ten meters and the water table is ground level.

And then the permeability of sand deposit is below the ground level is about ten power of minus three meter per second and this an average volume, and the depth of water level has to be decreased by about two meters below the excavation level.

So, in order to construct the building, dewatering has to be done by laying pumps at various junctions, calculate the rate of flow of water when one pump is laid and compare with discharge when number of pumps is increased.

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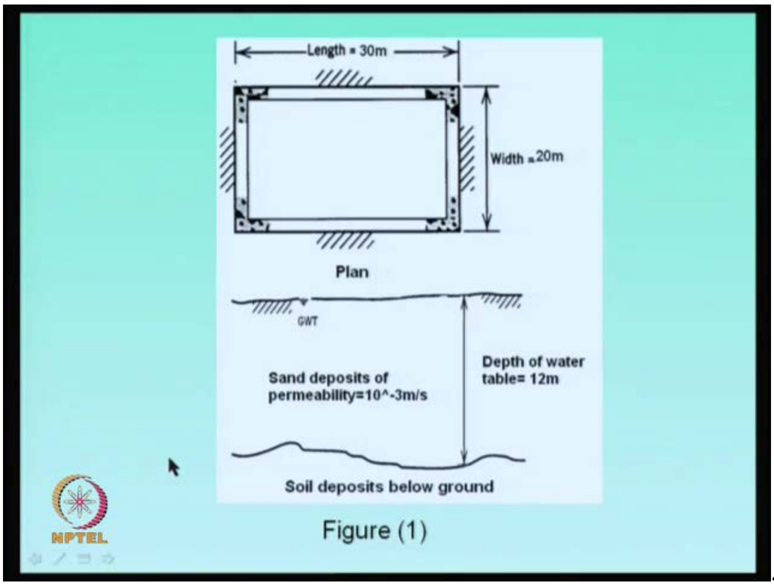

So, this is like we will try to resolve solve this problem, you have a 30 length is about 30 meters, so width is this and depth is about, depth of water table lowering required is 12 meters.

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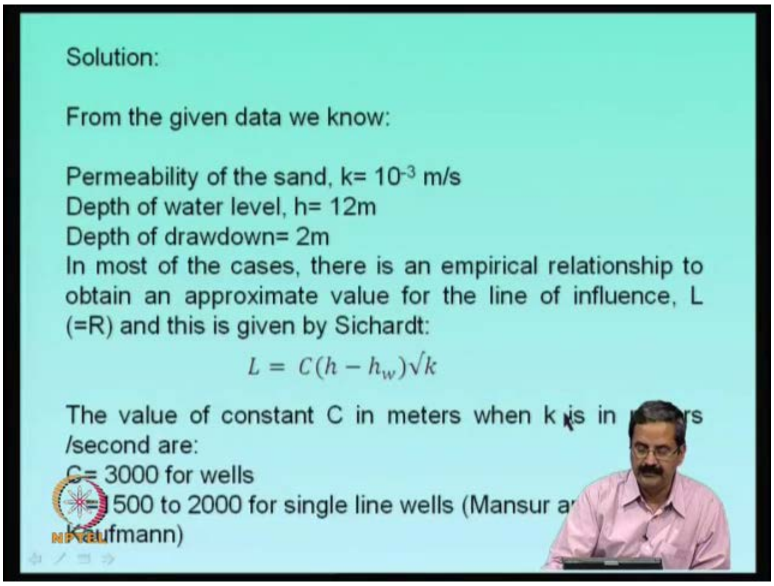

And what do we do is that, first thing is that, we should calculate, so we note down all the conditions required and the permeability values, 10 to power minus 3 meter per second is that value. Draw down depth of, draw down below the level is 2 meters and this is h is 12 meters, in most cases, there is an empirical relationship to obtained, the approximate value for the line of influence as I said is equal to, all this is given by this previous expression that I just mentioned. And you have some sort of expressions like this that are given in the text.

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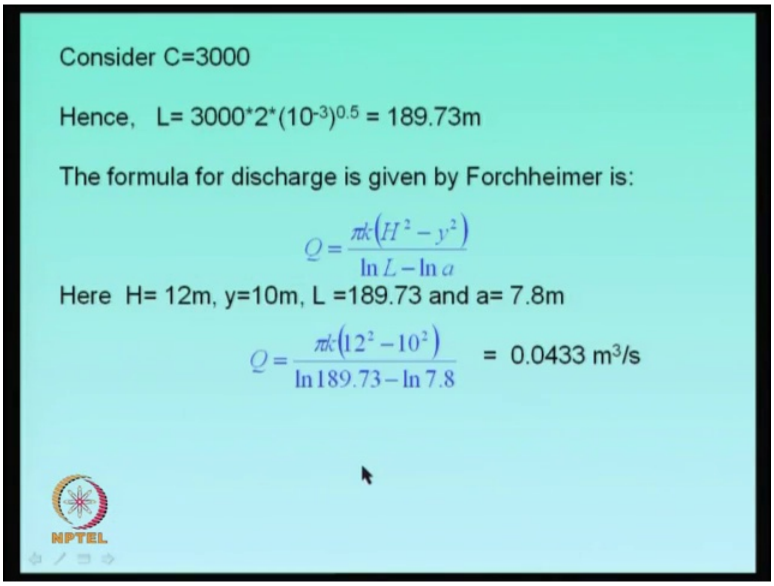

And once you use that for c equal to three thousand, you get a term called about one ninety meters or two meters close to that. And the formula for discharge is given by this equation and if you put all these numbers, you get about 0.043 three meter cube per second. So, this is actually, you know the discharge that the area has you know totally this amount of water that should be thrown out to see that you have that water table, it is does not there is not does not affect the construction of the foundation at 10 meters level.

Because ten meters level is coming into picture and then we are trying to take at least two meters down that, just this is an example, may be numbers and field applications could be different, I mean so, but then just to want to give a flavor of what could be done here, I am just trying to illustrate.

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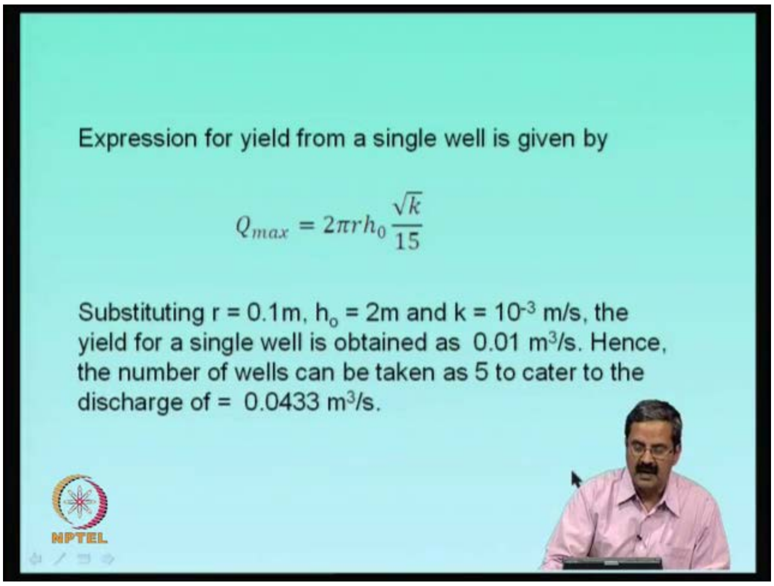

And expression for a single yield from a single well is given by an expression, which is actually an empirical expression that is given in (( )) and. So, you try to have the…, for substituting r equal to 0.1 meter, the radius of the single well and h naught equal to 2 meters, and k equal to minus 3, the yield for a single well is obtained as 0.01 meter cube per second.

Hence, you know, like we have seen that the total water to be removed is 0.0433 meter cube per second and this is some 0.01. So, you can take it as about 4.3 or something you will get, that you can say for the I mean conservative side, five wells are required, five wells or five well points are required to calculate the, to dewater the area, this is the an example here.

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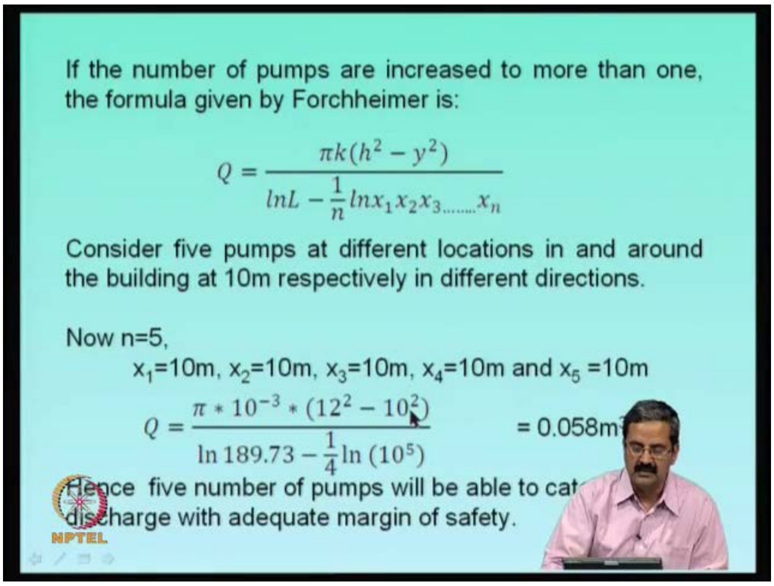

Now, see what the distances we should calculate, right are. So, if the number of pumps is increased to more than one, you know it is not easy to have high, I mean you should have a one pump of very high capacity, you know which is not easy sometimes. In fact, sometimes what happens is that, in most of the field applications, if one of the pumps goes wrong, there should be a factor of others should take care.

So, once they always have some efficiency factor that comes into picture here, so one should be very careful, so this particular equation gives discharge for a number of wells. Like you know if you have a number of wells, its x 1 and then the distances x 1, x 2, x 3, x n and take natural logarithm and 1 by n, is the number of pumps and use this in this example, we say that, as I just mentioned, we need 5 pumps.

And then we try to put at different locations, may be just like this x 1, x 2, x 3, some example, there is only an example here. So, you try put this and then calculate the numbers here and what you get is 0.058, which is more than 0.040433, right.

So, which is not bad, which is ok, you know it is better to have the higher, you know little margin here. So, that there is always that, you know if there is something wrong, no you always have some safety. So, hence x 1 with all these distances, of course many of these are just numbers, one can change then numbers and then get these things, what this means is that, one can get the, design the number of pumps required, based on the discharge required or the boundary conditions that we have for the given problem and also have adequate margin of safety. So, this is simple example illustrates that one can one can do a design of the dewatering system in a simple way.

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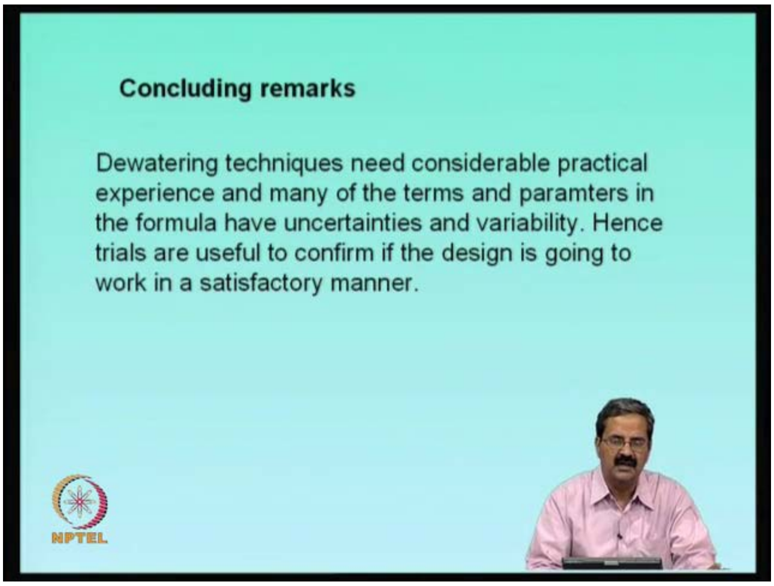

And of course, in this particular issue, one should understand that the use of the dewatering techniques needs considerable experience, for example, it is not easy, you know, you have specialized contractors who will have array of their systems, you know if one goes wrong, they can use something else. You know in a particularly, if dewatering goes wrong, it's very risky in foundations and lot of problems will ah come up all of a sudden.

So, one should understand that these techniques need lot of experience and many of the terms and parameters in the formulas of uncertainties in a variable, and then you need to trial actually. What I meant was that you should be able to do some sort of trials in actual design, say for example, you must try to try to do a simple trial in the field itself.

It is that I got permeability like this and then I got the water lower leveling, they need to measure also, in fact, they must measure the using pizometers and all that, what is the extent of lowering the observed. They have to do lot of some some measurements so that its quite useful in trying to see that their design is satisfactory, finally if it is not going to work in the field, it is very difficult to retrieve the situation, particularly if the water table problem is not solved, it is the project gets stopped, so that is very important thing, one should understand that. Many of the variables formula are somewhat empirical and they are highly variable also, like say for example, permeability value, there could be variations from point to point, so even if you take average value also, one should be little careful and one should design the system in a proper way.

So, with this, I have just completed dewatering and we have another system, how see the thing is that I just mentioned that dewatering, particularly when it is in clays, how do you do that. The thing is that, this is a very important and we use this concept, you know, because, we know that the clays are negatively charged particles and we try to use this ah concepts to dewater in the case of clays.

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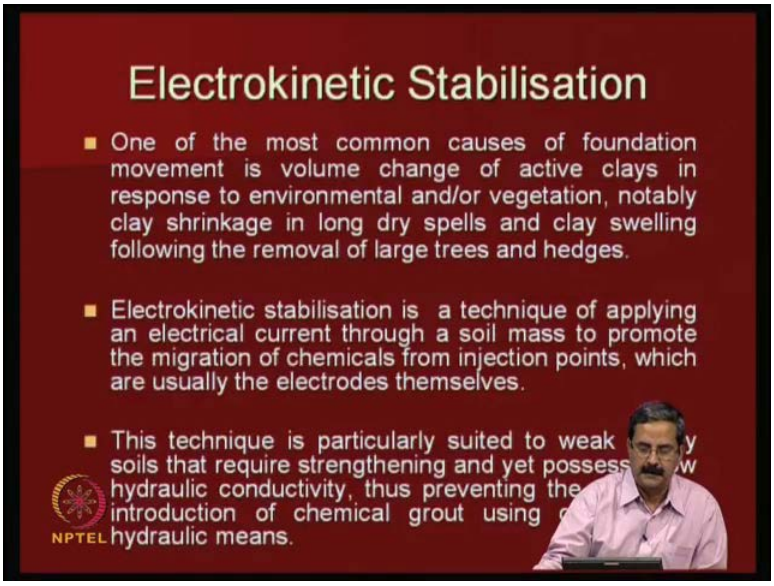

So, that is called electro kinetic stabilization that we will discuss. So, in this lecture, what I would be doing is that, I would be completing or covering a few issues on Electrokinetic processes and describe a few field trials of the technique. One of the most important causes of the foundation movement is a volume change of the active clays, for example, the bentonite clay or or even, say for example, expansive clay or any general clay.

You know soft soil has lot of issues, particularly in the presence of environment, like you know, for example, if there is a water content changes, there is a lot of swelling, you know water content is there it impacts, water there is a water content change, there is a swell. So, many of these clays have lot difficulties, particularly they have shrinkage and volume expansion and all that. And the electro kinetic stabilization is a technique of applying an electrical current through the soil mass to promote the migration of chemicals from injection points.

What we do is that, chemicals will, you know, we introduce also some chemicals, so that we also have a some injection wells and once you apply the electrical gradient, like electrical gradient you have a cathode and an anode, there is a movement of anions, and then that draws water with that. So, then the movement takes place because of the preferred orientation of the migration of ions, whether its cations or anions, then water is also moved in that process and with result that you have a stabilization occurring.

Actually, it is very useful to weak clayey soils that require strengthening and yet possess a low hydraulic gradient conductivity. So, the permeability is very low, so for example, if I want to do a consolidation in like consolidation process, it takes lot of time, even preloading and all that they work to some extent, preloading or even the technique of what you call discussed, we discussed vertical drains also. In fact, you may not believe vertical drains have been combined with this technique to accelerate the process further.

You know, it is not just, you know people have advance so much that in the initial stages we had only sand drains, now you have a the prefabricated vertical drains, you also have natural drains. Now, since it is have electrical system and you make some of the drains as electrodes and then you see the rate of water movement, like I have seen myself. Some actual experiments where the migration of water is so fast, like the moment we have an electrode, the there is an anode, there is cathode here and then you apply some 3 or 4 millivolts in a small tub, then the water, I know, within a few hours, say for example, I did an experiment once upon a time, where you have a plastic tub, in which the water content of the whole area was about eighteen percent and then it is compacted soil.

And you have a cathode, you have an anode and then we have applied some short of electricity between that, and then you know, when the water content was 18 percent, in both sides, after may be another 4, 5 hours or 6 hours, the whole in one side, there is a three percent only, the other case it was little higher, much higher, but then you know one can see that, to reduce the water content to such from 18 percent to say for example, 5 percent or whatever, it needs enormous stress in the field like.

You know pre-consultation or the load that you have to apply is so much, but here and then a time time is also another important variable and without going for loading or anything, you are able to just go by electrical forces, electrical gradients, you are able to withdraw all the water from once I one one electrode to other electrode just by voltage difference, because the it was compatible. In fact, this was required, why because, there was one software company and then you know they have constructed they have a flooring and everything, they did not see the that there is a water table level that existed about within a four, five meters down, down there very close to that and whatever.

So, the flooring that they have was not really comfortable, in the sense that, it is all wet, and then there is a water somehow it went capillary, because of the capillary raise of water, water even was you know you can see that the flooring totally it was it has lot of waviness in that.

And it was very uncomfortable in a very good software office, it is actually (( )) in sometime back, may be a few years back, may be a few years back. So, in that whole software office, when people go, it is suppose to be a people that is have excellent environment, where people work very comfortably, but you what we saw was that finally people are not able to use it well, because we have waviness, there is a water in some corners and you have all computer systems here.

So, when they approach the Indian Institute of science, I just did that experiment and look that the possibility, because already the building is existing and I cannot use all these systems of dewatering and all, not easy. So, we studied this electro kinetic stabilization as a in one of the courses and we did an experiment to see that, that is what I just mention that, we just took a plastic tub in which we introduce electrodes and then we try to find out the water content change after applying the electrical gradient.

So, we find that it was excellent and only thing it was required, it it needed a lot of practical experience in insulation of that particular system, because you know it is not easy. So, as I just mentioned, this technique is very useful to very weakly soils, and which has lot of I mean low permeability and so sometimes people also use chemical grouts also ok.

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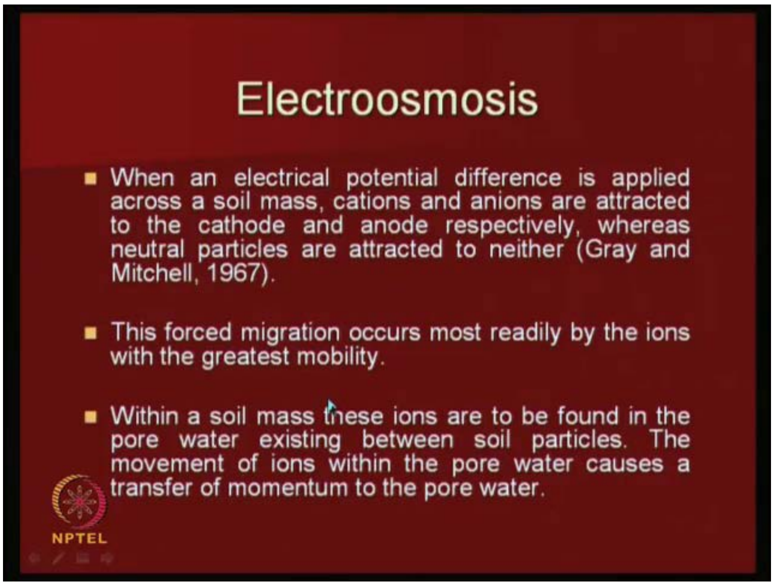

So, some of these things could be avoided if you have to go, if you can go for this type of technique. So, what what does it do? When an electrical potential difference is applied to a soil across a soil mass, cations and anions are attracted to the cathode and anode respectively, whereas neutral particles are attracted neither, that is you know actually there is standard reference by gray and Mitchell.

And this forced migration occurs most readily by the ions within the with the greatest mobility, say for example, you have different types of ions like sodium ions, potassium ions and calcium ions and all that in clays. What happens is that, the ions with greatest ability, like say for example, sodium, they can you know they it is a very comfortable system, in which you have you know you can they have a good mobility and then migration of water. Essentially we are looking at removal of water, removal of water occurs rather fast.

Within the soil mass, these ions are to be found in the pore water existing between the soil particles, the movement of ions within the pore water causes a transfer of moment to the pore water. Actually why is it happening? we know that in a clay, clay is negatively charged particle and the thing is that you have adsorb water on the clay surface and also beyond that you have a pore water. Pore water also has certain chemistry, like you know it has its p h, it has its ionic concentration and all that, so the this water adsorb water is different from the pore water. So, this concept is very important (( )) students of soil mechanics, I must have studied all all of these.

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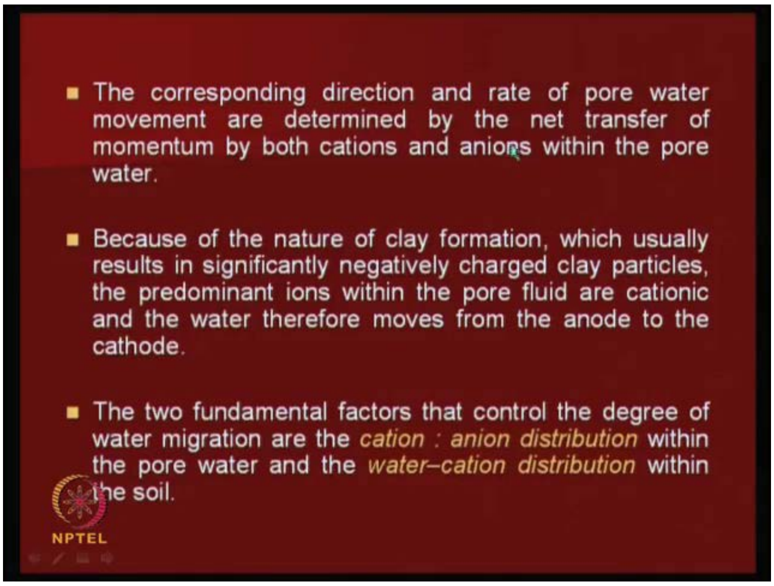

And the corresponding direction rates of pore water movement are determined by the net transfer, the movement by both cations and anions within the pore water. So, how how is a water movement taking place, is essentially by the nature of momentum, you know the thing is that how many ions are you know see getting altered or distributed you know. There is so many mechanisms that you have, the this based on the theory of diffuse double layer, in which you know the clay surface is a treated as layer.

And next to that, because of the electro osmosis process, we have negatively we have negatively charged particles and then there is always a positive ions trying to go towards them, trying to balance out the valency. So, because of the nature of clay formation, which usually results in significantly negative charged clay particles, the predominant ions with the pore fluid are cationic and water, therefore moves from the anode to cathode.

So, what happens is that, the near the cathode you have lot of water like you know as I said, predominant ions in the pore water, say for example, sodium ions or calcium ions move with the pore fluid or they are they are they go towards the you know cation you know cationic and therefore, you know they they go towards cathode, right cathode moving ions.

So, all the predominant ions move towards the and from anode to cathode, this is very important concept and so if you have a system of pumping water near the cathode, it is fine. Two fundamental factors that control the degree of water migration or the action anion distribution, like you know, say for example, cation and distribution, how many cations you have? How many how many anions you have? And what is the distribution and all that within the pore water and the water cation distribution? So, for example, in the water, how much what is a cation exchange capacity of the soil is one important variable here?

Then, even the ion ionic concentration of the free waters, then all these chemical analysis needs to be done in a proper way, right.

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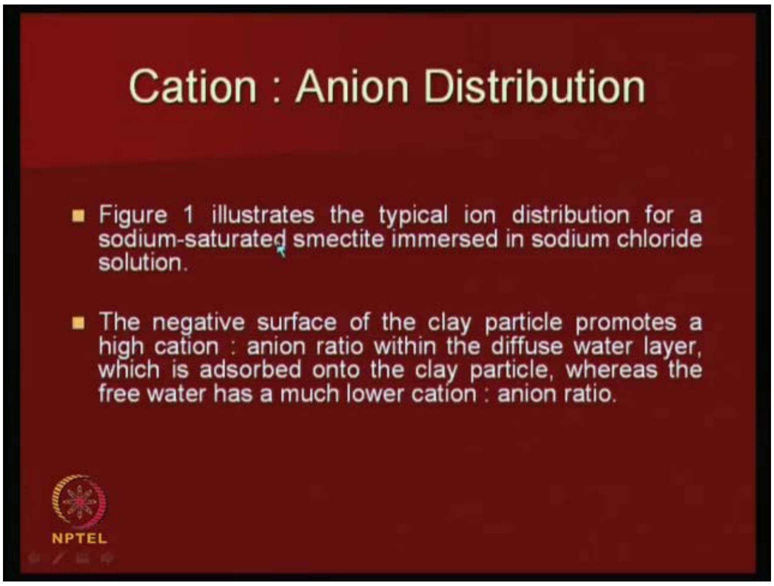

So, I will just show you a figure in which you have a typical ion distribution for a sodium-saturated smectite smectite or a bentonite immersed in a sodium chloride solution. The negative surface of the clay particle promotes a high cation anion ratio and within the diffuse level diffuse double layer diffuse double layer. Actually we know that next to the clay surface, we have a diffuse double layer formation and which is nothing but the adsorbed layer next to the clay particle we say and free water has a much lower cation anion ratio.

So, the negatively charged surface of the clay particle has a high cation anion ratio quite naturally, because you have lot of negative charge surfaces, so cations tend go there, so the cations in anion ratio could be high within the diffuse double layer. Whereas, in the clay, free water, definitely the cation anion ratio is lower, this needs to be appreciated.

A theory I explaining the degree to which anions may migrate from the free water to the diffuse double layer and the associated effects on the electro osmosis was formulated by donnon 1924. In fact, you have anions in the free water, how many of them like will go to the diffuse double layer? And associated effects are given in a particular book, particular reference, but it was quite useful in understanding, the many of the there could be some difficulties, because it was formulated little last century may be, but the understanding that it gave us quite useful, in understanding this phenomenon of stabilization of soils using this electro kinetic mechanisms.

Because it helps in controlling the chemical changes, because it has there are number of variables here, one is a p h of the water, then the adsorbed be a water content and also the physical behavior of clay

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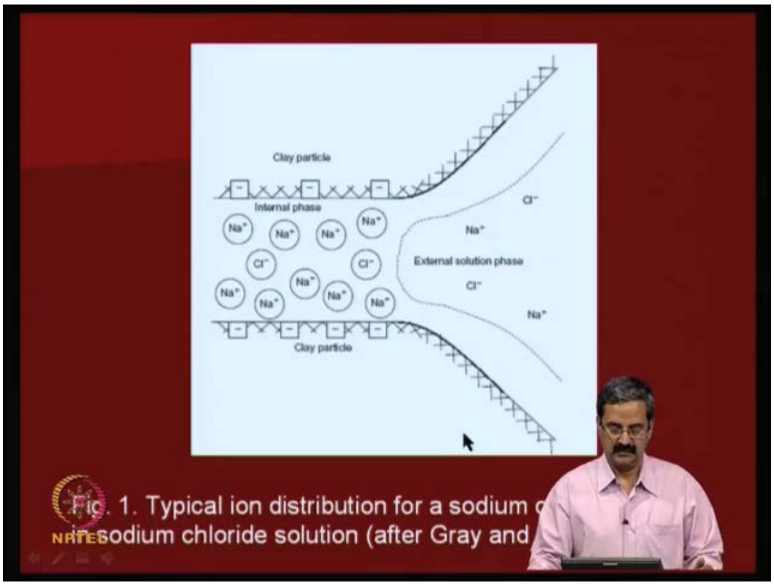

So, this is what I just mentioned, these are all negatively charged particles, you have the clay particle. This is another clay particle and you have sodium ions here, which are there in this internal phase. External solution phase, this is another one, in which you have the so excess, you know the thing is that these are all balance here, but then these are all excess ions.

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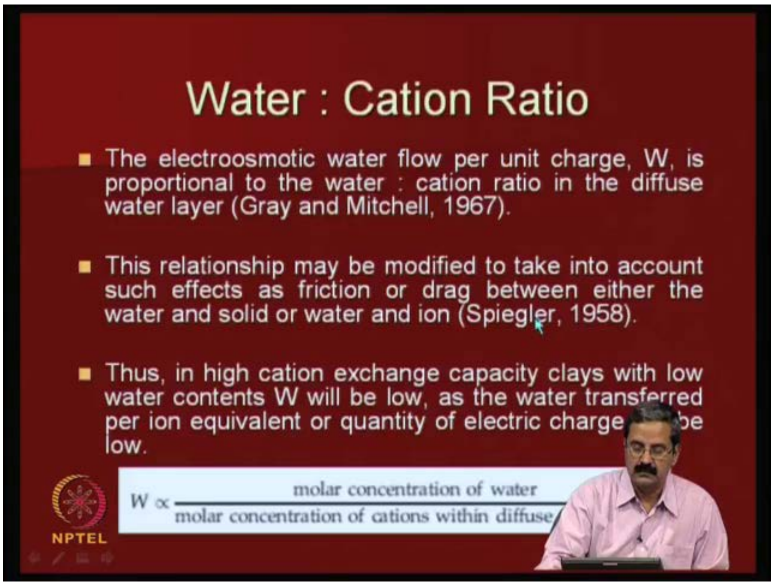

So, this water cation ratio is something that is very important and the the purpose here is that, we would like to remove water, we may call it electro osmotic water, because electro osmosis is a force that is applied to remove the water. So, we try express in terms of the charge, unit charge w, is proportional to water cation ratio quite obviously, because higher is the amount of water present, higher is the amount of, higher is amount of water cation ratio, higher is amount of water you can withdraw. You know if the water content is going to be less, you do not have much opportunity to remove water, so the electro osmotic water flow per unit charge, we call it because you know it is more chemistry based terminology, which we should understand, because the chemistry is very important in this context.

So, the electro osmotic water flow per unit charge is proportional to the water cation ratio in the diffuse double layer. The relationship may be modified to take into account such effects as friction or drag between both the water and the solid or water and ion. So, there could be some drag effects, because it is all a number of ions and different types of ions being present, but still what happens is that, so you can see this equation, where water or electro water is proportional to the ratio of molar concentration of water divided by molar concentration of cations within the diffuse level diffuse double layer.

We know what is molarity? Molarity is nothing but one molecular weight dissolved in one liter of water, right or the solute or whatever. So, we essentially need to understand those terminology and as we can see that this amount of water that you can get out of this system is a function of the molar concentration of the water and also inversely proportional to the molar concentration of cations within the diffuse double layer. Like say if you have more concentrations in the diffuse double layer, they hold the water; you know free water will not come.

So, it is the to that extend it has that meaning here that the high cation exchange capacity clays with low water contents, the w will be low, that is what I just mention. Say for example, if the clay surface has high negative charge, definitely the molar concentration of cations will be higher. You know, because they go there, you know so the water, so the this is an important, so thus in the high cation exchange capacity clays with low contents, w will be low, low water content means the availability of water itself will be low and as the water transferred per ion equivalent or quantity of electric will be low.

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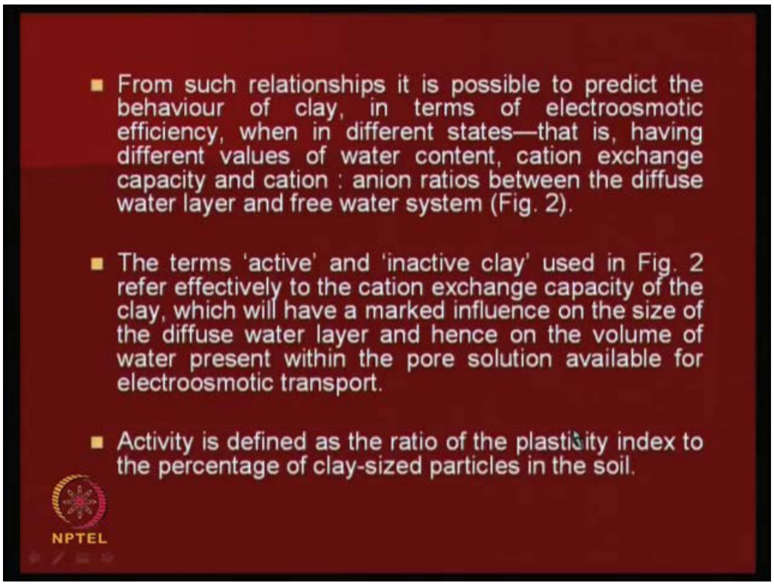

Like you can see that from such relationship it is possible to predict the behaviour of clay in terms of the electro osmotic efficiency, like we try to cal it in terms of the electro osmotic efficiency. It is having different water contents, like you know you can say that if it is in a dry state or a wet state or even close to optimum moisture content, one can find out some of these properties.

So, the amount of water that we can expect is a function of the water content, the cation exchange capacity and the cation anion ratio between the diffuse double layer and the free water system. There is another term that we should see, that the terms active and inactive are something that are related to the size of the diffuse double layer and hence on the volume of the water present within the pore solution available for electro osmotic transport.

What it means is that, if the clay is very active, how do you define the activity of the clay? Activity is defined as a ratio of the plasticity index to the percentage of the clay sized particles. So, p i we have some number, divided by the percentage of the clay particles is what we define as activity. And if the material is active, what does it mean? Active in the sense, actually this activity is defined in terms of the negatively charged surfaces and definitely the um you can see that this activity and inactivity whatever, has a significant influence, we will see in this particular figure that inactive low exchange capacity and high water content.

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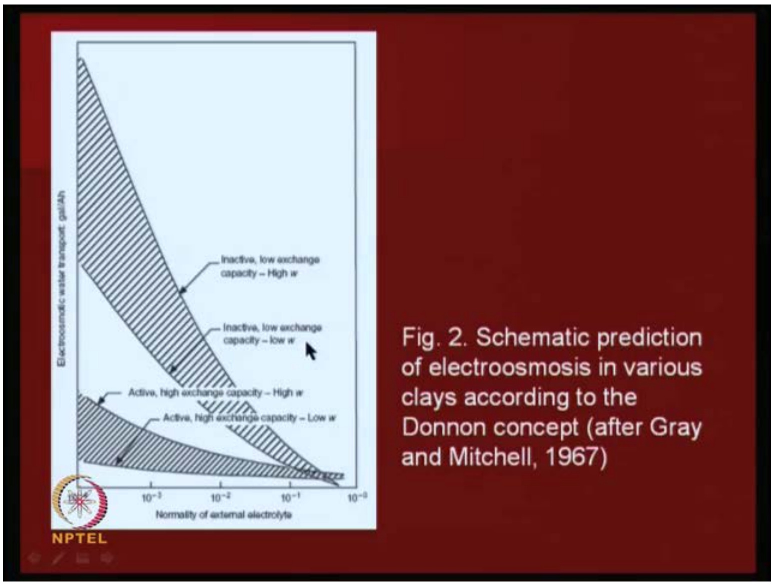

The water content, one can have a very high water content removal from that, inactive low water content, low exchange capacity and low water content, it is another one. And very active, like you know, the you to say for example, bentonite and all that, and high exchange capacity and high water content is one, and then definitely active high exchange capacity low water content. If water availability is there, definitely you will have a higher yield of the water content removal from the soil, because of the electro osmotic forces, right.

So, the electro osmotic forces are quite useful in removing the what the water. So, this also in fact one should know that it is the function of the molarity or the normality. See normality of the external electrolyte is is again another variable and these two terms normality and molarity, and molality, they are all you know we studied in our basic sciences, in the in our curriculum.

And say for example, molarity is nothing but the you know as I just mentioned, you know you take a sodium chloride and it has a molecular rate of forty and if it is dissolved in one liter of water or the solute, whatever you call it, we call it one one molar. And normality comes in terms of the equivalent weights, it is much more standardized and we we talk in terms of the normality also. And the higher is a normality, like you know, say for example, its one here, 0.1 here, 0.01 point, so you dilution you had dilution factors of that, like instead of one liter, you will say only hundred ml, so dilution is there. And so based on the dilution factors also, you has a significant role, this is what we understand from the clay science.

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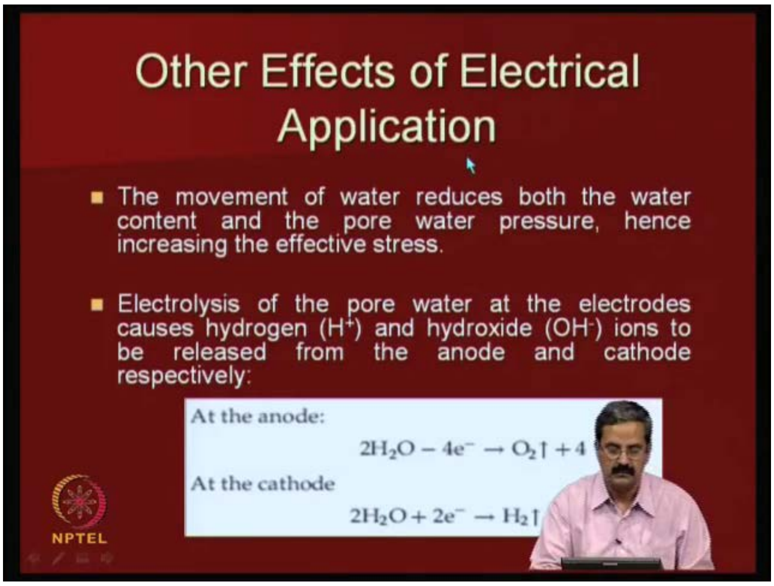

What are the other effects of electrical application? So, once we apply the electrical gradients, what happens is that, the movement of water reduces both the water content and the pore water pressure, so it increases the net effective stress. So, the moment there is an effective stress increase, there is an effective strength also, strength is increasing, right.

Then, you have electrolysis of the pore water at the electrodes, so you have the electrolysis taking place, which causes hydrogens and the hydroxyl ions to be released from the anode. And there is a sort of you know you have h plus and o h minus ions getting released and you have this sort of chemical reactions taking place, right, because this is what happens.

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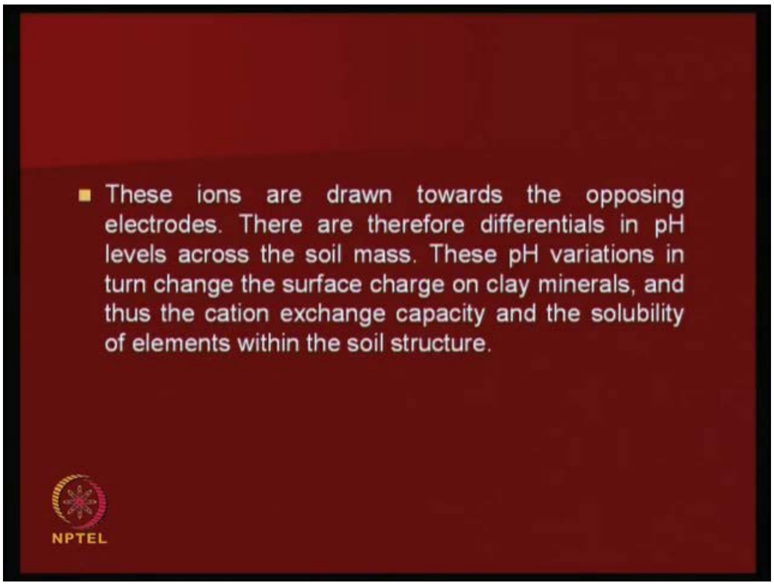

These ions are drawn towards the opposing electrodes; therefore there are differentials in pH levels across a soil mass, you know because of the changes in electrical gradients, there could be pH variations also. So, these pH variations in turn change the surface charge of the clay minerals and thus the cation exchange capacity. See what happens, the originally cation exchange capacity was something very different, so for example, we say that betonies has so much cation exchange capacity or this iolite has so much c e c b quality cation exchanges capacity.

So, all that gets altered and also because of these changes, you know when the migration of ions takes place from cathode, from anode to cathode and cathode to anode, whether it is hydraulic hydroxyl ions or hydrogen ions whereas, so, there is change in the soil structure itself, so that leads to in fact somewhat stronger condition here, that is within the soil. So, what happens when you have electrodes? The reactions that occur between the electrodes and the pore water depend on the characteristics of the pore water and the material properties of the electrodes.

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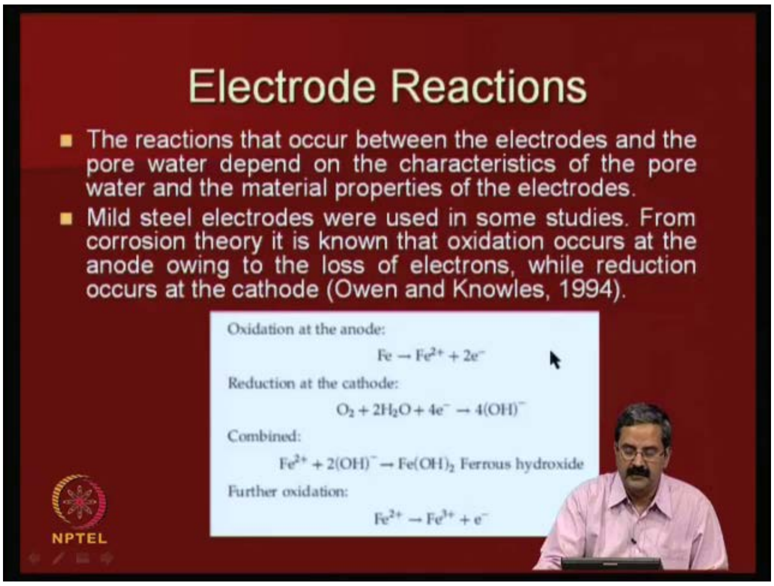

So, suppose you are using mild steels, what happens is that, definitely be when you put a water, corrosion takes place, right. So, this is what happens like iron gets converted into ferric material and so there is this sort of chemical reactions and oxidation at the anode takes place, reduction in the the cathode takes place, you have combined influence like this. So, they again, it gets to ferrous to ferric, it gets converted and this sort of chemical reactions (( )) takes place and which is something, which even we we are familiar with some sort of corrosion that could occur.

So, mild steel electrodes will use in some studies, which is quite, you know quite standard material. From the corrosion theory we know that the oxidation occurs at the anode owing to the loss of electrons, while reduction occurs at the cathode, this is what is shown by this two chemical reactions and you have a combined also, so further oxidation takes place ok.

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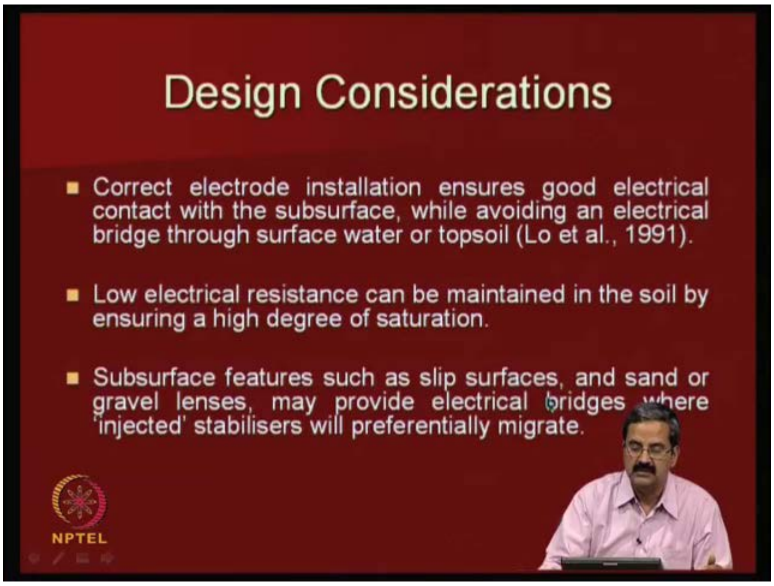

So, this having this knowledge, how do you go about design? It is actually we do not have much work that is done in India, but elsewhere in the rest of the world, there is considerable knowledge expertise or at least lot of practical studies have been done. In fact, in 1963 itself, in 1960 if you remember, casagrande you know who is known as one of the top top researchers or the engineers in geotechnical engineering.

He contributed to this, you know he is the first man who showed demonstrated that the stability of the slope can be improved using electro osmosis, he did some experiments. So, what is required in this some of the issues we should discuss, then correct electrode installation, say we have a cathode, we have an anode and it should have good electrical contact with the sub surface. There is a clay soil and a once you put this material like you know anode and cathode, they are small tubes, it can be just which you can put inside or it can be bigger like hundred in the field.

What I did in the lab was a small tubes, because its comfortable, they are available, so I just put because my clay you know the small plastic container was about one and half to two feet higher and then I just put some tubes, which were acting as anodes and cathodes.

So, correct electrical electrode installation requires are ensures good electrical contact with sub surface, they should be properly there. While avoiding an electrical bridge through the surface or the topsoil what happens? There should not be you know a short circuiting type of thing, where you know the there is a, that is get that bridge formation should be avoided; low electrical resistance can be maintained in the soil by ensuring high degree of saturation. Sometimes, if we just add water and all that degree of saturation is higher and then maintain that systems. You know we have essentially, we all we would like to avoid the bridge formation from short circuiting, sub surfaces such as slip surfaces and sands gravel lenses may provide electrical bridges, where injected stabilizers will preferentially migrate.

Actually what we do is that, say sometimes you know in see in the inceptive soil, there could be some small slip surfaces some gravel and all that, the possibility is that even through them the electrical bridges can form, which to be avoided. So, why because, actually we inject in this whole technique some short of stabilizers and the possibility is that the stabilizers will get migrate into the system that we we would like to avoid.

Then you have how do you do this? auguring or Augured holes may have to be sleeved to prevent infill, side wall raveling are collapse, in Which case selection of sleeve material requires careful consideration.

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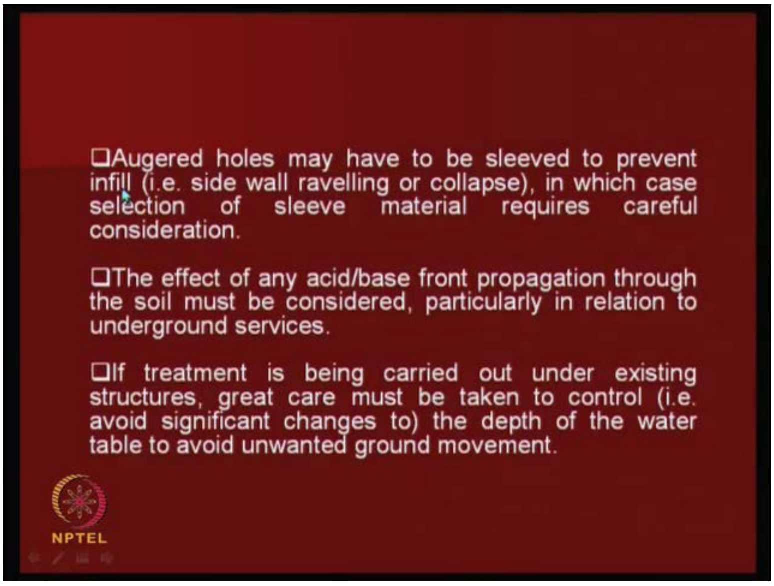

Say for example, you are trying to make a hole, so the hole should be able to work in a proper way, so that it should not collapse, so the sleeve material selection is an important factor. Then the effect of any acid or base front propagation through the soil must be considered particularly in relation to underground services.

Actually when you are trying to do in an an excavate in some area, in an urban area or something, where you have a lot of underground structures like p v c pipes and many other chemical or even steel pipes or anything, service lines, one should be very careful that. Say for example, the some of the distribution of cations and anions should not lead to damaging the underground services that is important point.

If the treatment is being considered carried out to under existing structures, great care must be taken to control the depth of water table to avoid unwanted ground movement, actually that is another important point. As I just mentioned that the water table control is very important, like water table you can remove in one place, but at the same time, where it is important, the you should maintain the water table by again putting water back at least close to that foundation area, so that we do not want to increase in effective stress in the below the foundation. We only want water removal somewhere, not in a we need the foundation also, so one should be very careful in removing the water, particularly close to foundations.

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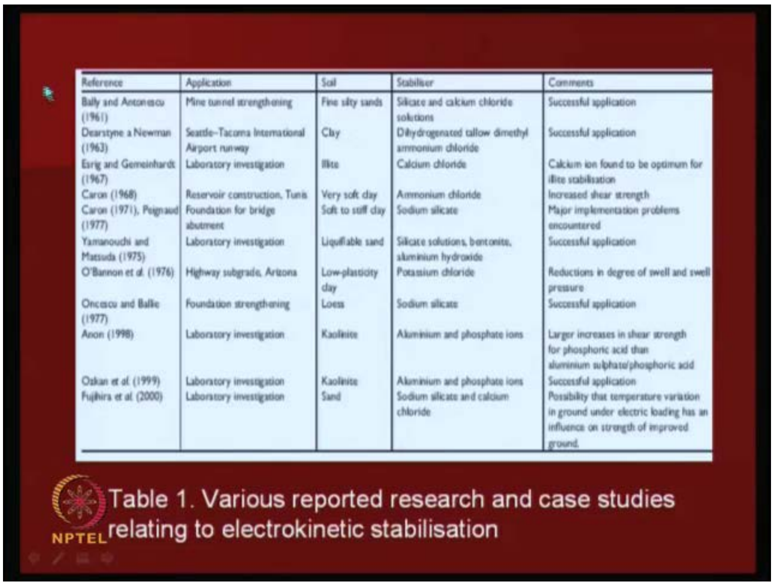

Reference	Application	Soil	Stabiliser	Comments
Bally and Antonescu (1961)	Mine tunnel strengthening	Fine silty sands	Silicate and calcium chloride solutions	Successful application
Dearstyne a Newman (1963)	Seattle–Tacoma International Airport runway	Clay	Dihydrogenated tallow dimethyl ammonium chloride	Successful application
Esrig and Gemeinhardt (1967)	Laboratory investigation	Illite	Calcium chloride	Calcium ion found to be optimum for illite stabilisation
Caron (1968)	Reservoir construction, Tunis	Very soft clay	Ammonium chloride	Increased shear strength
Caron (1971), Peignaud (1977)	Foundation for bridge abutment	Soft to stiff clay	Sodium silicate	Major implementation problems encountered
Yamanouchi and Matsuda (1975)	Laboratory investigation	Liquifiable sand	Silicate solutions, bentonite, aluminium hydroxide	Successful application
O'Bannon et al. (1976)	Highway subgrade, Arizona	Low-plasticity clay	Potassium chloride	Reductions in degree of swell and swell pressure
Oncescu and Balke (1977)	Foundation strengthening	Loess	Sodium silicate	Successful application
Anon (1998)	Laboratory investigation	Kaolinite	Aluminium and phosphate ions	Larger increases in shear strength for phosphoric acid than aluminium sulphate/phosphoric acid
Ozkan et al. (1999)	Laboratory investigation	Kaolinite	Aluminium and phosphate ions	Successful application
Fujhira et al. (2000)	Laboratory investigation	Sand	Sodium silicate and calcium chloride	Possibility that temperature variation in ground under electric loading has an influence on strength of improved ground.

Table 1. Various reported research and case studies relating to electrokinetic stabilisation

So, this is a typical example, a actually this is a number of lot of research has been done and the number of the paper published on this lines; for example, bally and antonescu in

1961 ok. This is a paper on, you know the application was mine tunnel strengthening, say you are trying to do tunneling and then you know when you want to the strengthen the tunnels, one should really use some short of stabilizers, also proper stabilizers so that all this things, electro kinetic stabilization is a is successful.

So, the soil type was fine salty sands, silicate the stabilizer use was silicate and calcium chloride solutions, because to accelerate the process in that thing, one should use this, the application the comment it was successful. And then there is another paper, where in a Seattle Tacoma, in u s international airport run way, the soil is clay and they have used some sort of stabilizer, dehydrogenated tallow diethyl ammonium chloride, whatever, then their application was successful.

Then, there is another paper, where is it laboratory study, the soil type of iolite and calcium chloride was used, calcium ion found to be optimum for iolite stabilization, so they were trying look at calcium ion and does it help. There is another paper on carom reservoir construction n Tunis Tunisia, very soft soil ammonium chloride was used, it increases shear strength.

Then there are some more papers again, foundation for bridge abutment, soft to stiff clay sodium silicate was used as a in carom stabilizer, there was major implementation problems encountered, that is one thing you know. Then yamanouchi and Matsudo in 1975, you have laboratory studies liquefiable sand, people use silicate solutions in betonies and aluminum hydroxide, so the application was successful.

So, you have cannon 1976 highway sub grade Arizona (( )), low plastic, clay potassium chloride, so reductions in the degree of swell and swell pressure that was there. Then there is another one 1977, foundation strengthening, it is a loess deposit sodium silicate was used as solution, it is a successful application.

Anion again it is a laboratory study, kaolinite was the clay soil type, aluminum and phosphate ions were used, large increase in shear strength for phosphoric acid than aluminum sulphate, they observed shear strength values. You know, say for example, they took two types of ions aluminum and phosphate and they find that you have an excellent benefit from the phosphoric ions. You know, phosphate ions and this an laboratory studies kaolinite, aluminum and phosphate ions, it successful laboratory investigations. So, you have number of studies that really that were quite helpful in giving a confidence to the professions in use of this technique.